

Windiana 2011, July 20-21, 2011

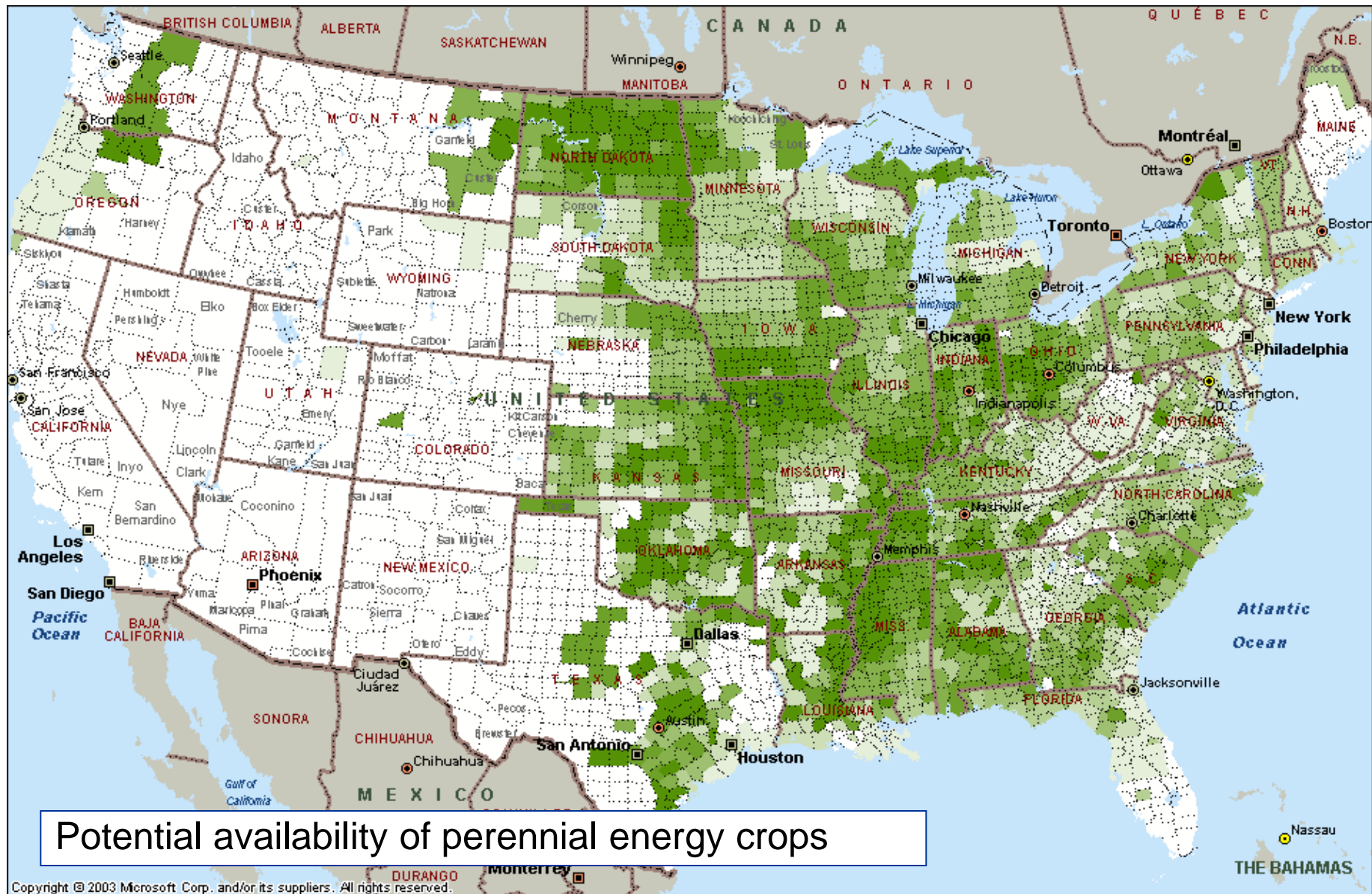
Logistical Challenges and Technologies Needed for Supplying Biomass for Bioenergy

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Agricultural and Biological Engineering
Mechanical Engineering (*by courtesy*)

Outline

- Why has lignocellulose biomass not achieved its promise?
- Challenges with biomass delivery
- Understanding and developing efficient biomass feedstock supply pathways
- Challenges with biomass feedstock handling



Source: Robert Perlack. Oak-Ridge National Laboratory, U.S. Department of Energy, AETC, Feb. 14, 2006

Biorefineries from cellulose biomass

1. We have an abundance of cellulose feedstocks
2. Conversion technologies are showing commercial promise
3. So why don't we have commercial cellulose biorefineries springing up?

U.S. Department of Energy Small-Scale Biorefineries (Cellulose feedstocks) Project Overview - up to \$240M USD

JULY, 2008

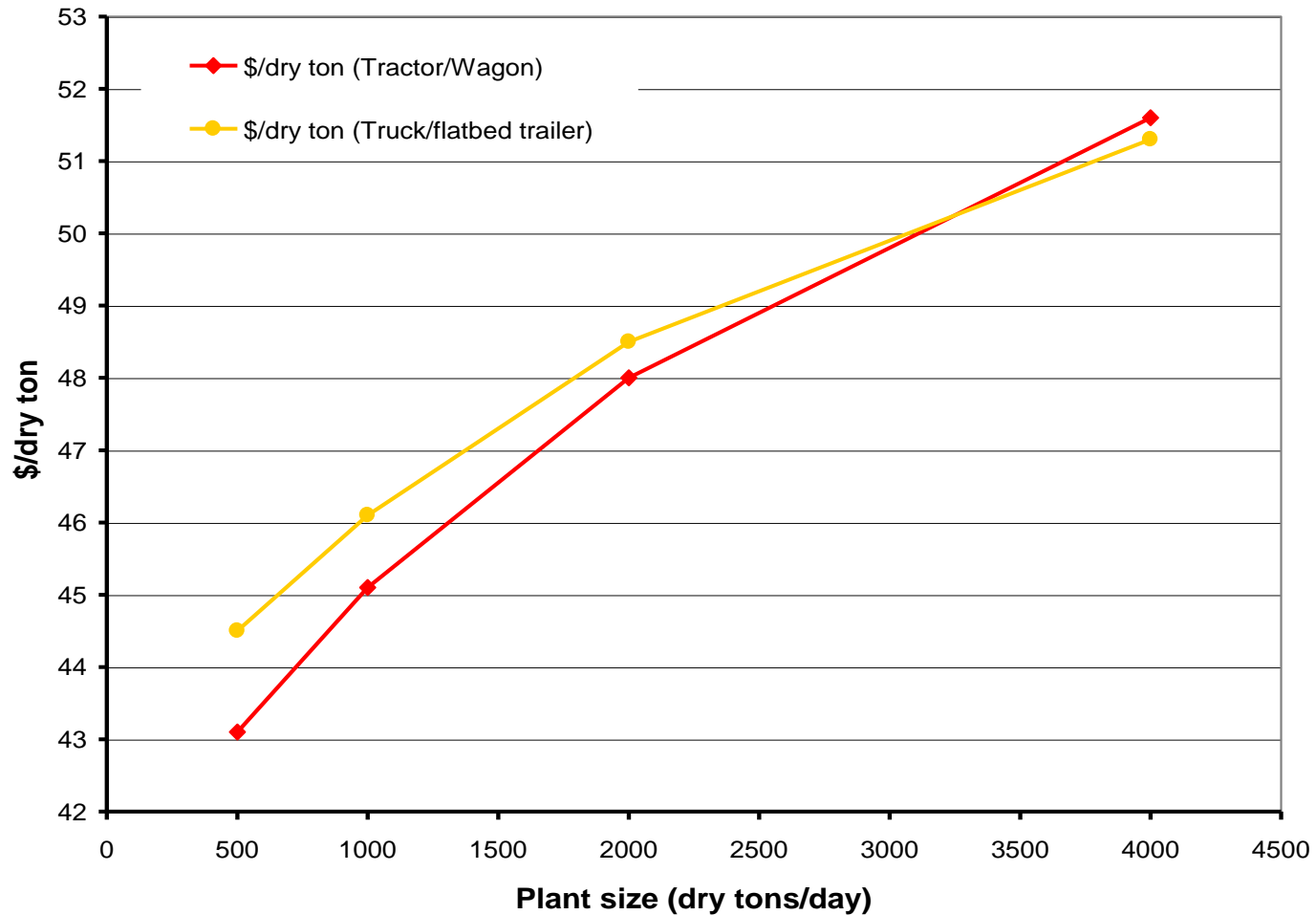
| Applicant | Total Cost | DOE Share | Cost Share | Annual Production capacity (Gallons) | Project Location | Feedstock | Technology |
|--------------------|---------------|--------------|------------|--------------------------------------|-----------------------|--|--|
| Verenium | \$91,347,330 | TBD* | TBD* | 1,500,000 | Jennings, LA | bagasse, energy crops, ag waste, & wood residues | Biochemical |
| Flambeau LLC | \$84,000,000 | \$30,000,000 | 64.4% | 6,000,000 | Park Falls, WI | Forest residues | GTL (FT) |
| ICM | \$86,030,900 | \$30,000,000 | 65% | 1,500,000 | St. Joseph, MO | Switchgrass, Forage sorghum, stover | Biochemical |
| Lignol Innovations | \$88,015,481 | \$30,000,000 | 66% | 2,500,000 | Commerce City, CO | Woody Biomass - agricultural residues | Biochem-organisolve |
| Pacific Ethanol | \$73,040,000 | \$24,340,000 | 67% | 2,700,000 | Boardman OR | Wheat straw, Stover, Poplar residuals | Biogasol |
| New Page | \$83,653,212 | \$30,000,000 | 64% | 5,500,000 | Wisconsin Rapids, WI | Woody Biomass - mill residues | GTL (FT) |
| RSE Pulp | \$90,000,000 | \$30,000,000 | 67% | 2,200,000 | Old Town, Maine | Woodchips (mixed hardwood) | Biochemical |
| Ecofin, LLC | \$77,000,000 | \$30,000,000 | 61% | 1,300,000 | Washington County, KY | Corn cobs | Biochemical (Solid State Fermentation) |
| Mascoma | \$136,000,000 | \$25,000,000 | 82% | 2,000,000 | Monroe, TN | Switchgrass and Hardwoods | Biochemical |

Challenges with Feedstock Logistics

- Limited understanding of biomass feedstock supply for commercial fuel or power production
- Lack of feedstock supply chain infrastructure
- Handling and Conversion systems not robust and flexible to handle different feedstocks
- Feedstock storage and handling not adequately studied and integrated with conversion systems
- Studies have not really integrated farm-gate-to-reactor delivery of the conversion chain
- Monitoring for quality is challenging
- Market uncertainties and risk of loss (by fire or spoilage) in storage are very high

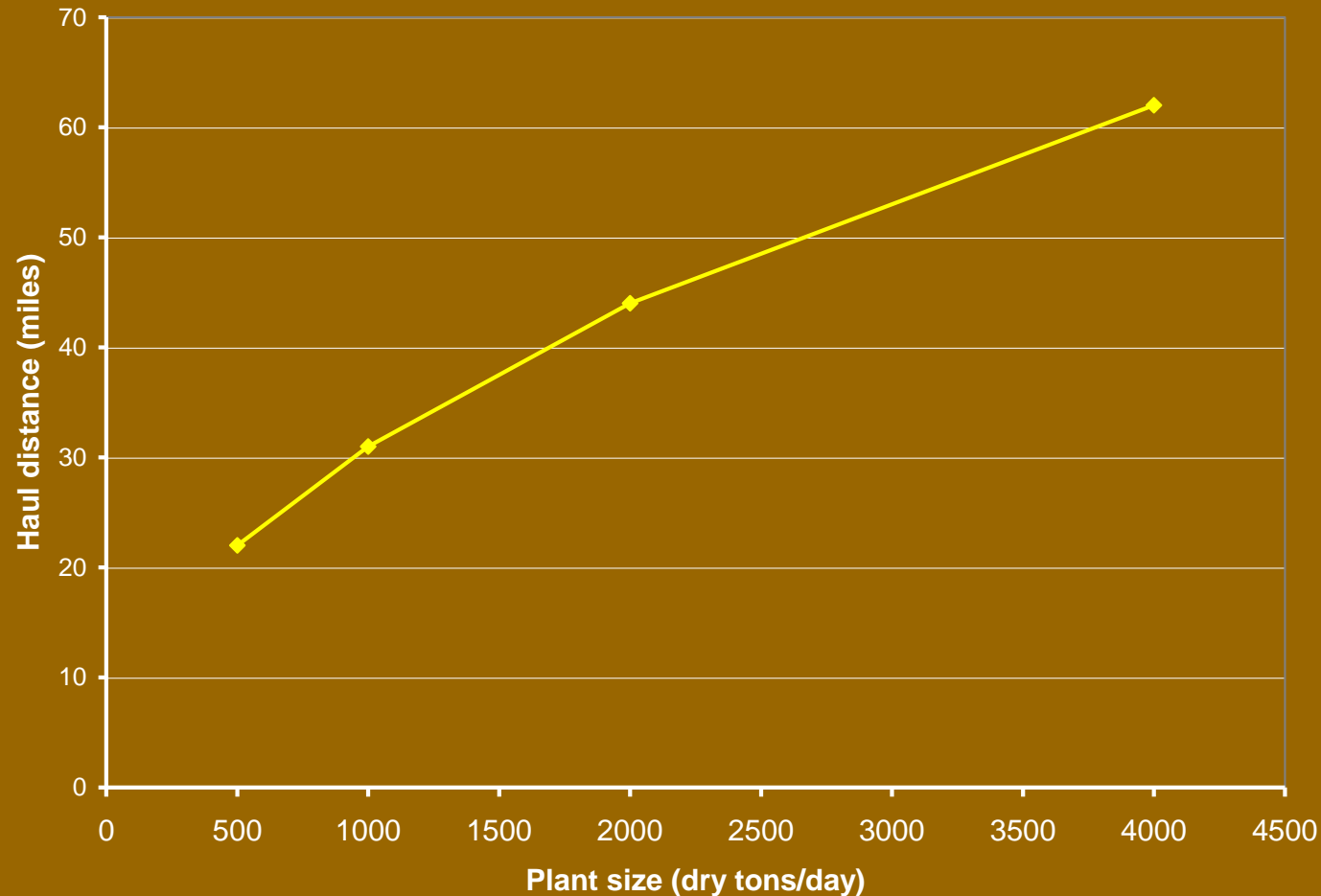


Cost per dry ton vs. plant size for delivering stover in bales



Source: Perlack, R. D. and Turhollow, A. F. 2003. Feedstock cost analysis of corn stover residues for further processing.

Haul distance vs. plant size for trucking stover in bales



Source: Perlack, R. D. and Turhollow, A. F. 2003. Feedstock cost analysis of corn stover residues for further processing. Energy 28 (2003) 1395-1403.

Conventional pathway for corn stover delivery with current technology

Collection methods:

Multiple operations:



Cutting & shredding,
windrowing, baling.

Delivered as bales



Transport by trucks

Cost at biorefinery

\$43.10/dt for 500
dt/day biorefinery
to

\$51.60/dt for 4000
dt/day biorefinery

**Economies of scale
are offset by
increased transport
cost !!!**

The Logistics Challenge with Biomass

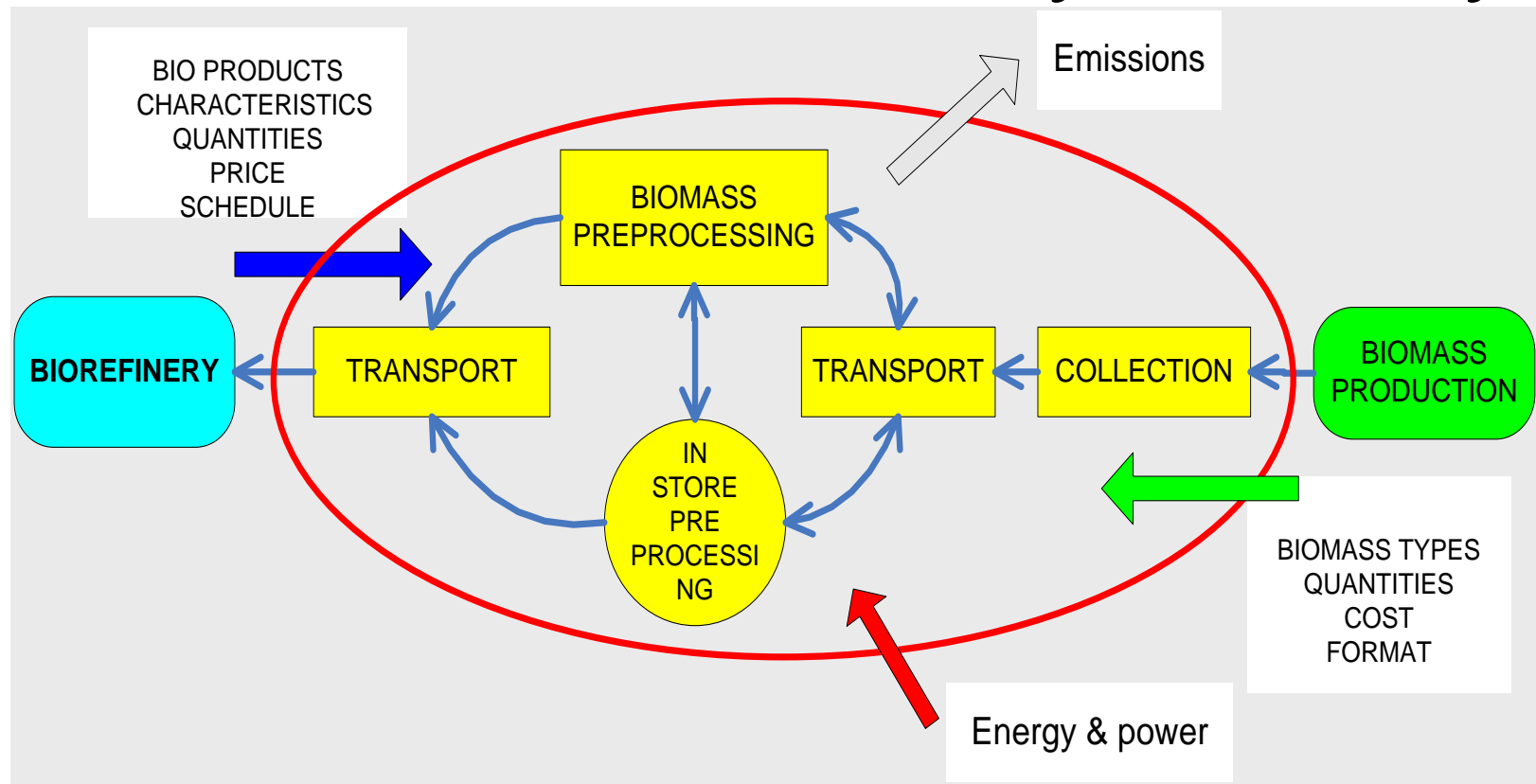


*How can we cost-effectively **access** from **Production (Field)** the vast variable amount of available biomass across the landscape and deliver to the **Biorefinery Reactor** year round*

Goals for Optimum Biomass Feedstock Delivery and Conversion

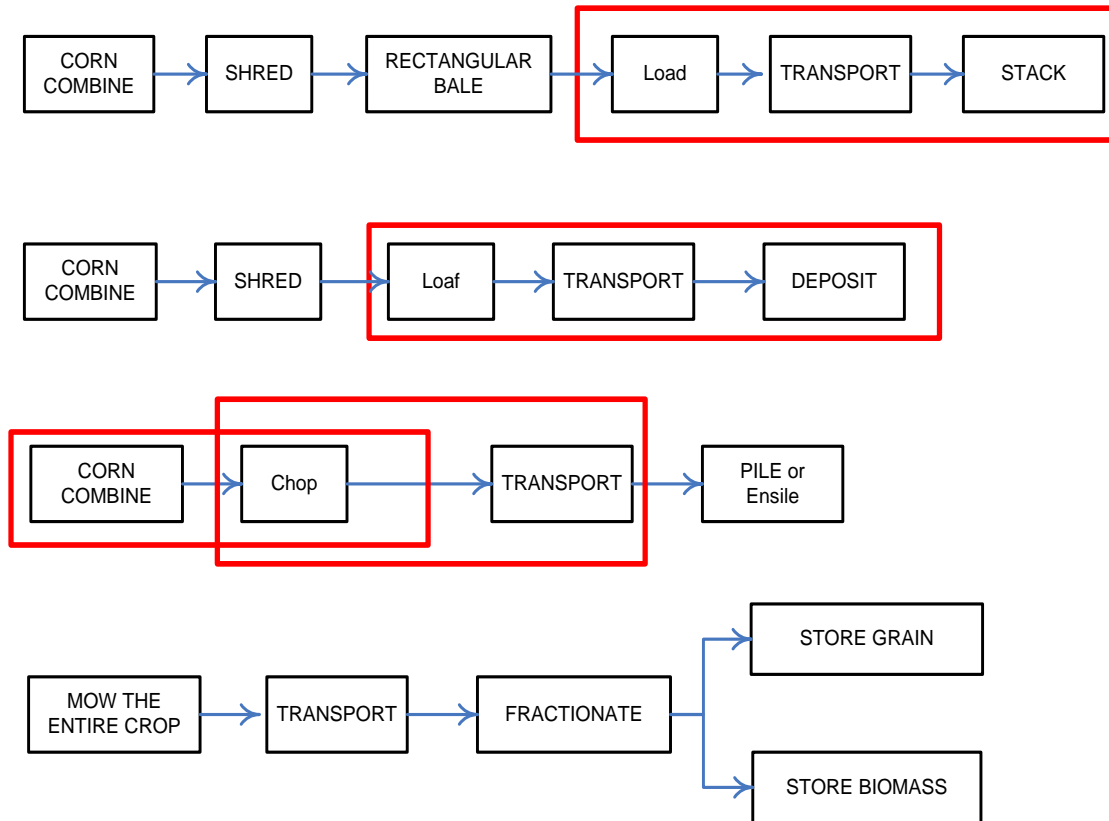
- Any cost-effective pathway to optimize biomass feedstock delivery for fuel/conversion must not only reduce feedstock transportation cost, but must also
 - optimize the quantity of fermentable sugars or BTU delivered at the plant-gate
 - be cost effective and profitable to producers
 - optimize handling and conversion efficiency and reduce downstream processing cost
 - be sustainable with minimal impact to the environment
 - have a positive net energy value

Components of Biomass Production to Biorefinery Pathway



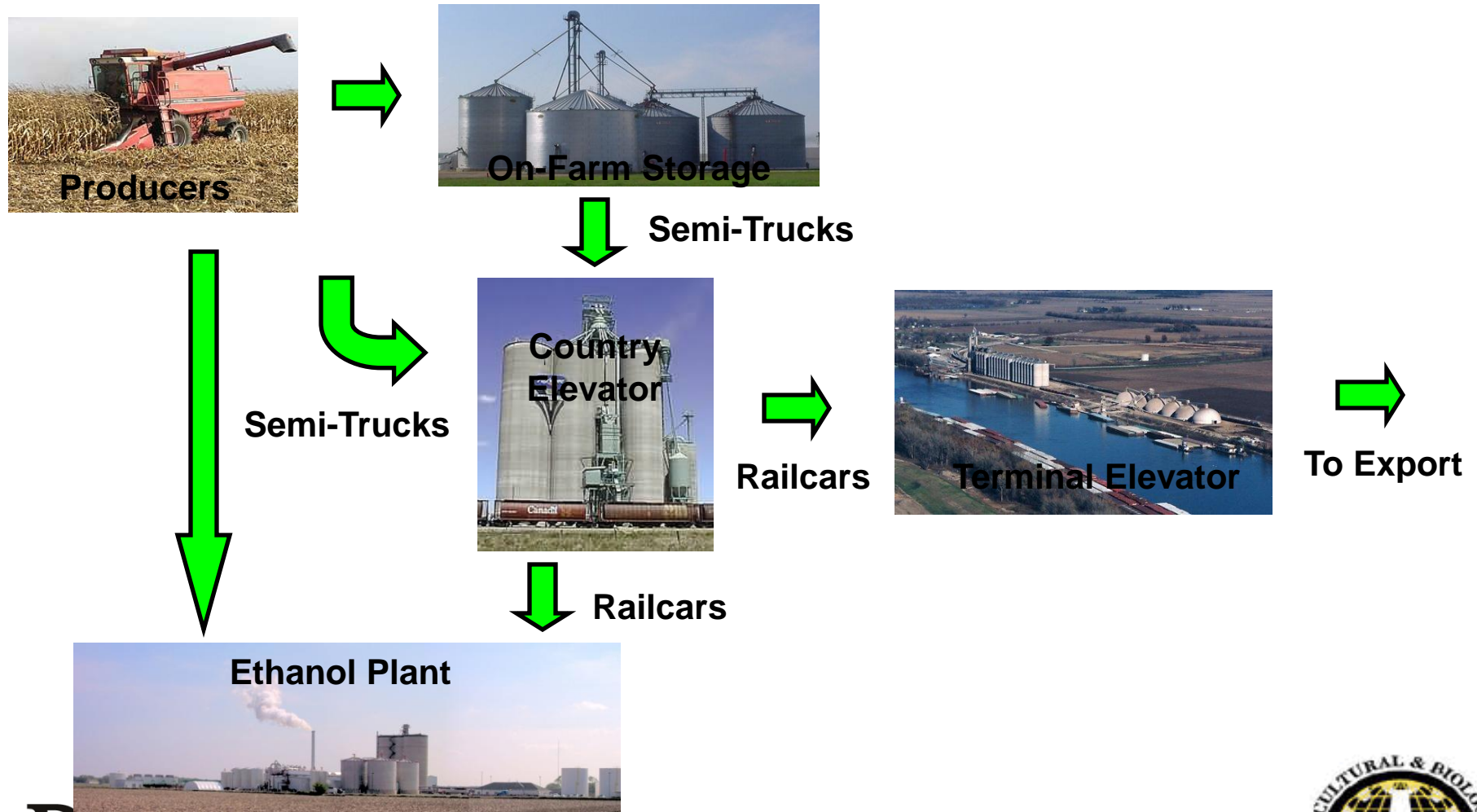
Source: Ileleji, K.E., S. Sokhansanj and J. Cundiff. 2010. Farm-gate to plant-gate delivery of agricultural feedstocks from plant biomass for biofuel production. In: *Biofuels from Agricultural Wastes and Byproducts* by H. Blaschek, T. Ezeji and J. Scheffran, Chapter 7. Wiley-Blackwell Publishing, Ames, Iowa.

Options for Collecting and Stacking Stover



Source: Ileleji, K.E., S. Sokhansanj and J. Cundiff. 2010. Farm-gate to plant-gate delivery of agricultural feedstocks from plant biomass for biofuel production. In: *Biofuels from Agricultural Wastes and Byproducts* by H. Blaschek, T. Ezeji and J. Scheffran, Chapter 7. Wiley-Blackwell Publishing, Ames, Iowa.

U.S. Grain Delivery Channel



Supplying Corn Stover Through Corn Grain Supply Channels

■ Why corn supply channels for stover?

- Corn grain and stover are from the same production entity (plant material)
- Pathway with least technological hurdles and cost
- Grain supply infrastructure and transport logistics is highly developed
- Most likely corn ethanol plants will be the first adopters of cellulosic ethanol technology, i.e. both corn grain and stover supply routes will be the same

Pathways of Biomass Supply - Systems Integration to Optimize Logistics



Producers



On-farm storage



JIT Transport to Country Elevator



Biorefinery

Railcar Trucks

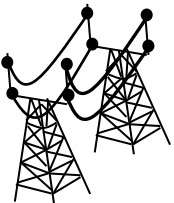


Country Elevator

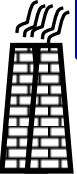
- Cleaning (Nutrient recycling)
- Sorting & Size Reduction
- Grading
- Blending
- Compaction for bulk transport



Preprocessing into upgraded drop-in feedstock



Power



Heat

CHP

Co-locating fuel & CHP

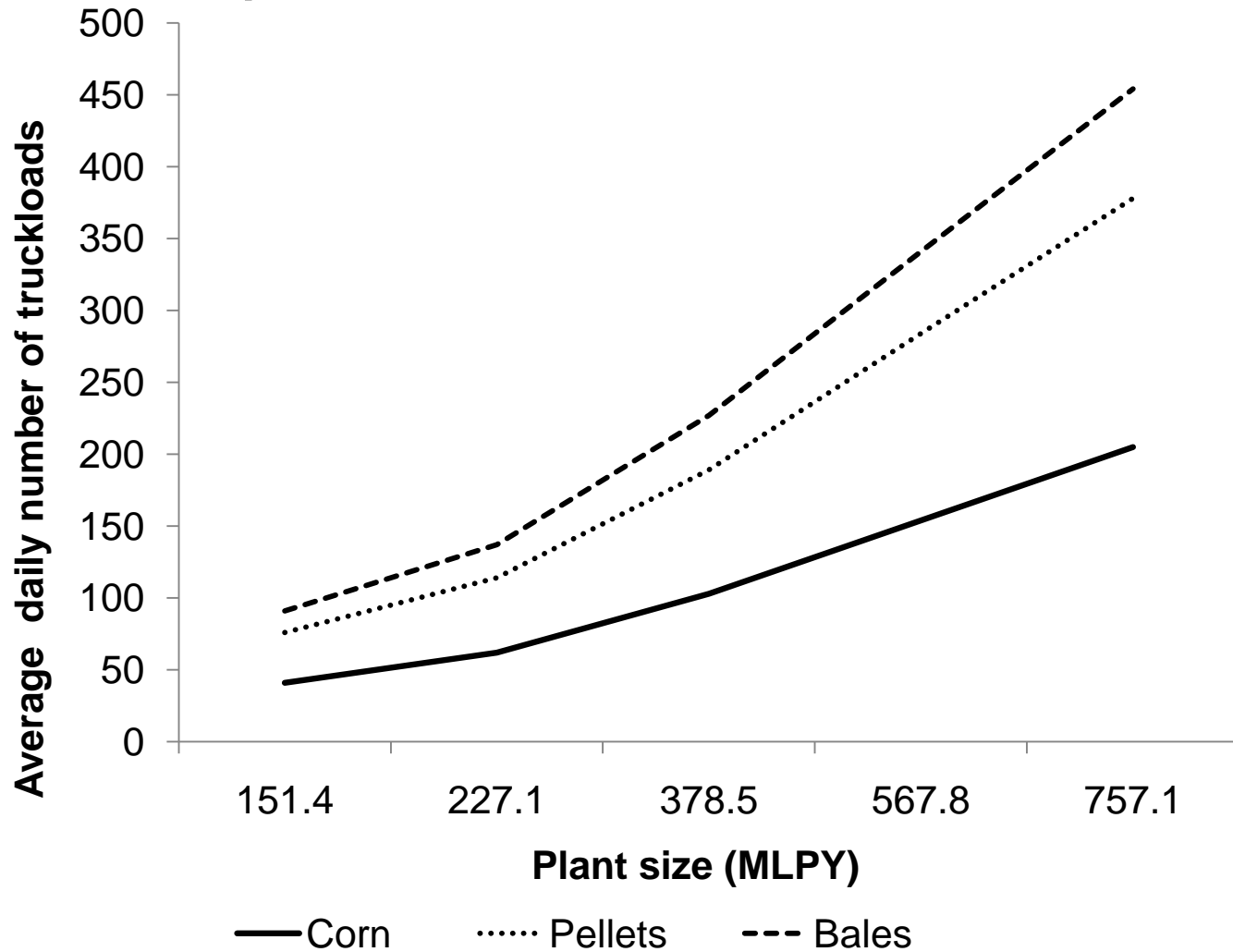
Other value-added products

Densification must be part of the solution

| Form of biomass | Shape & size characteristics | Bulk density (kg/m ³) |
|------------------|-------------------------------|-----------------------------------|
| Chopped biomass | 20 – 40 mm long | 60 - 80 |
| Ground particles | 1.5 mm loose fill | 120 |
| Ground particles | 1.5 mm pack fill with tapping | 200 |
| Briquettes | 32 mm diameter × 25 mm thick | 350 |
| Cubes | 33 mm × 33 mm X-section | 400 |
| Pellets | 6.24 mm diameter | 500 - 700 |

Source: Sokhansanj, S and J. Fenton. 2006. Cost benefit of biomass supply and preprocessing. A BIOCAP Research Integration Program Synthesis Paper, Canada

Average daily requirements of truckloads at the ethanol plant (Krishnakumar and Ileleji, 2010)



Storage requirements and costs for corn grain (10 days inventory).

| Capacity (MLPY) | Inventory Required (Mg) | No. of Bins | Volume of Each Bin ^[a] (cu.m) | Diameter of Bin ^[a] (m) | Storage Cost (\$ Mg ⁻¹) |
|--------------------|-------------------------------|----------------|--|--|---|
| 151.4 | 10,390 | 2 | 7,150 | 18.3 | 34.6 |
| 227.1 | 15,585 | 2 | 10,725 | 22 | 34.6 |
| 378.5 | 25,975 | 2 | 17,875 | 27.4 | 27.1 |
| 567.8 | 38,962 | 3 | 17,875 | 27.4 | 27.1 |
| 757.1 | 51,949 | 3 | 23,833 | 32 | 27.1 |

^[a]Source: (Commercial Grain Bin Specifications, GSI Grain Systems, 2009).

Source: Krishnakumar and Ileleji, 2010

Storage requirements and costs for bales (10 days inventory).

| Capacity (MLPY) | Inventory Required (Mg) | Area of Storage (m ²) | No. of Bale Handlers | Storage Cost (\$ Mg ⁻¹) |
|--------------------|-------------------------------|---|----------------------------|---|
| 151.4 | 14,431 | 35,055 | 9 | 82.1 |
| 227.1 | 21,646 | 52,583 | 13 | 79.7 |
| 378.5 | 36,076 | 87,637 | 21 | 77.8 |
| 567.8 | 54,113 | 131,456 | 30 | 77.3 |
| 757.1 | 72,151 | 175,273 | 40 | 76.3 |

Source: Krishnakumar and Ileleji, 2010

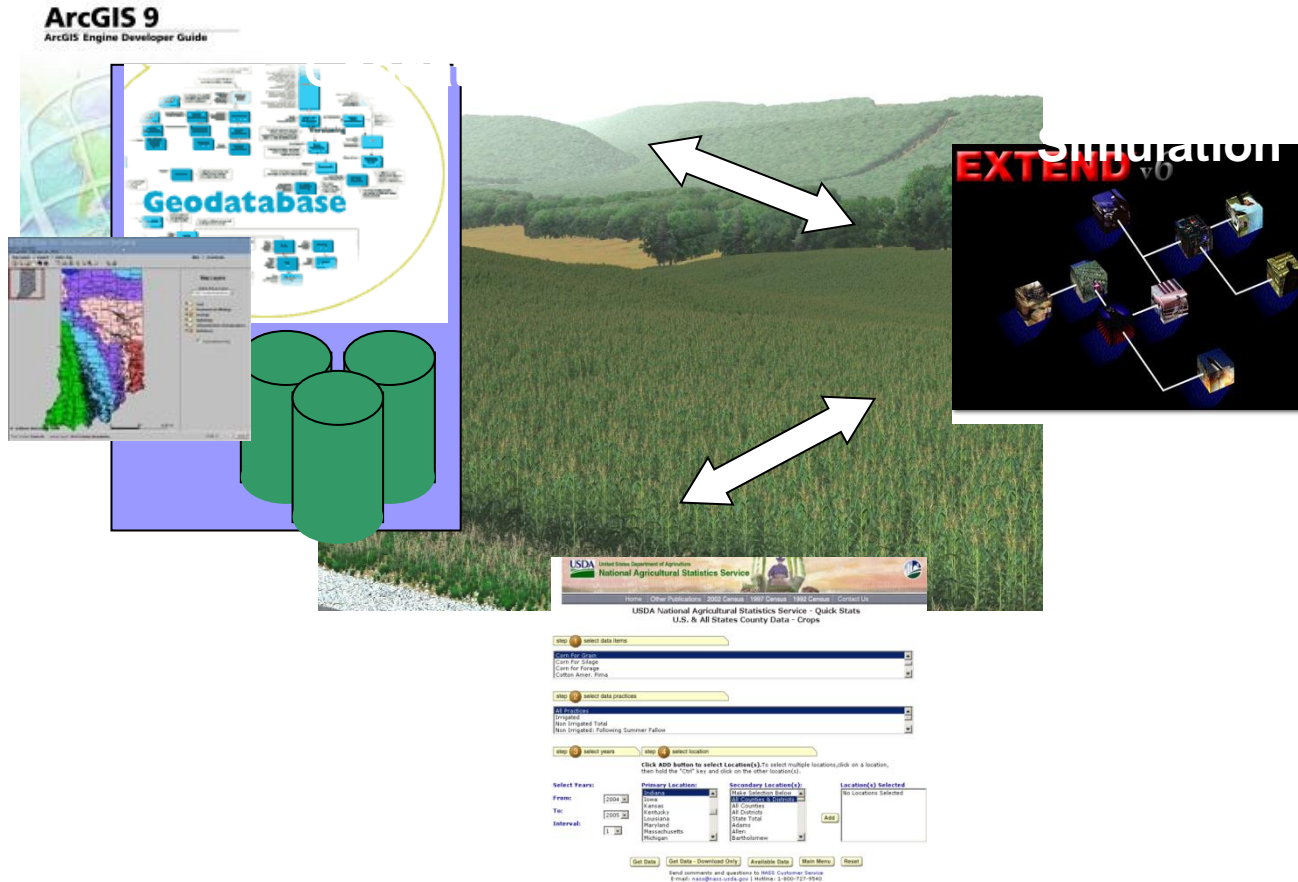
Storage requirements and costs for pellets (10 days inventory).

| Capacity (MLPY) | Inventory Required (Mg) | No. of Bins | Volume of Each Bin ^[a] (cu.m) | Diameter of Bin ^[a] (m) | Storage Cost (\$ Mg ⁻¹) |
|--------------------|-------------------------------|----------------|--|--|---|
| 151.4 | 14,431 | 2 | 13,228 | 23.77 | 32.8 |
| 227.1 | 21,646 | 2 | 19,482 | 32 | 24.4 |
| 378.5 | 36,076 | 3 | 22,046 | 32 | 24.4 |
| 567.8 | 54,113 | 5 | 19,842 | 32 | 24.4 |
| 757.1 | 72,151 | 6 | 22,046 | 32 | 24.4 |

^[a]Source: (Commercial Grain Bin Specifications, GSI Grain Systems, 2009).

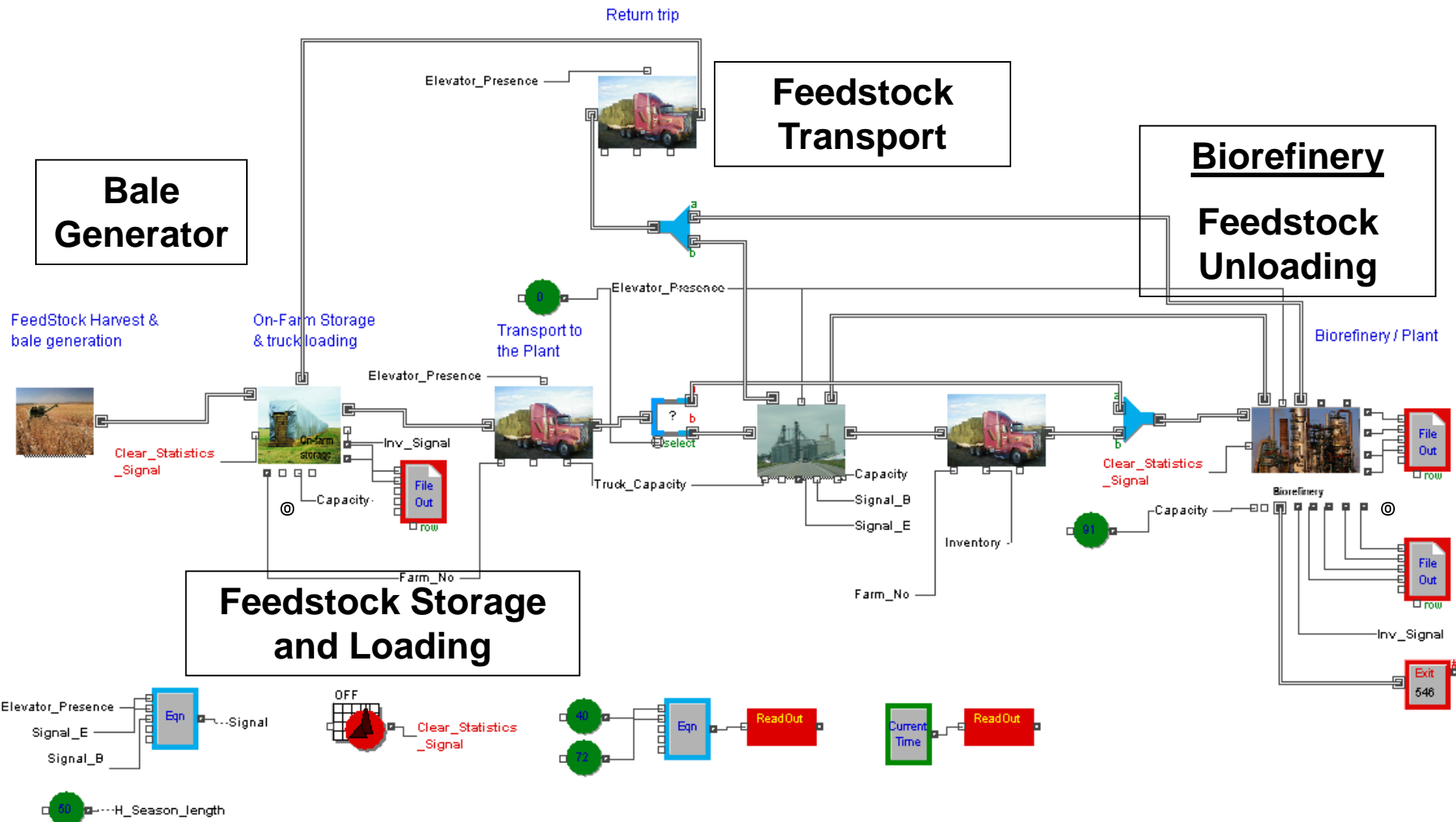
Source: Krishnakumar and Ileleji, 2010

Modeling Structure of BmFLS



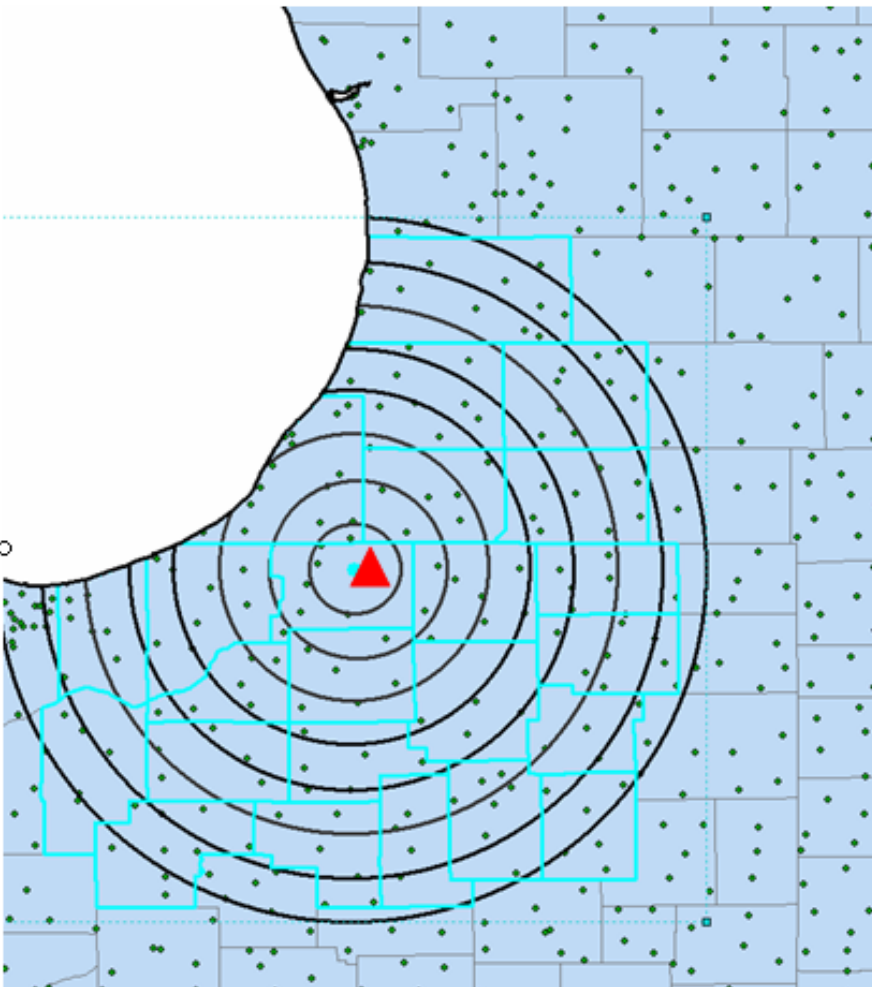
Biomass Feedstock Logistics Simulator - BmFLS

Primary Model Blocks of the BmFLS Simulator



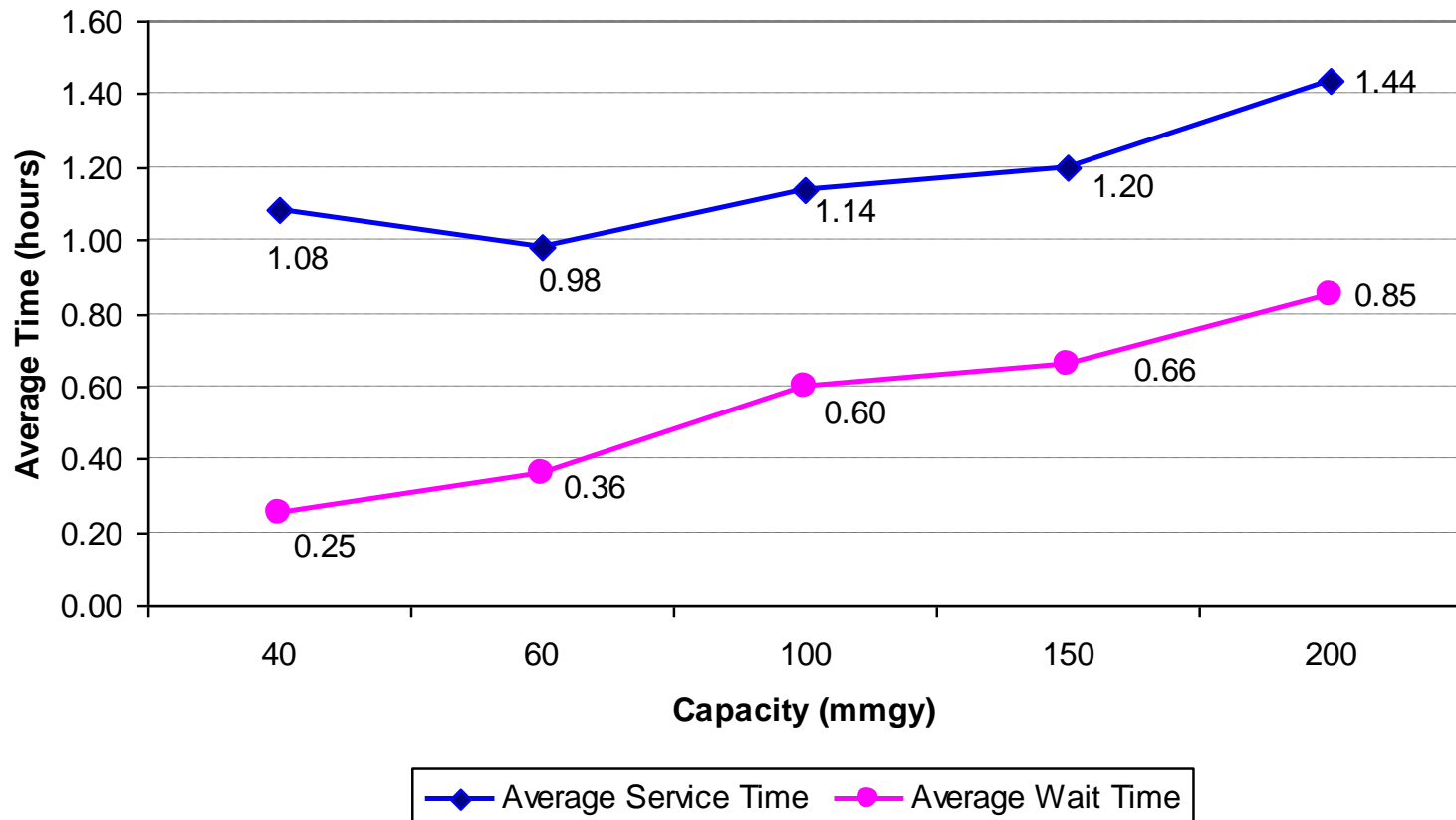
The unit load that moves serially through the blocks was modeled as a truckload of feedstock, 39 bales (900 lb of 8' × 4' × 3') per truck

10 Corn Stover Availability vs. Distance



| Counties | | Distance (miles) |
|--|--|------------------|
| Allegan, Porter, St. Joseph, Kalamazoo, Lagrange, Pulaski, Noble, Jasper, Cass, Miami, Wabash, Whitley, White, Huntington | | 70 |
| Allegan, Porter, St. Joseph, Kalamazoo, Van Buren, La Porte, Starke, Lagrange, Kosciusko, Fulton, Pulaski, Noble, Jasper, Cass, Miami, Wabash, Whitley | | 60 |
| Porter, St. Joseph, Elkhart, Kalamazoo, Van Buren, La Porte, Starke, Lagrange, Kosciusko, Fulton, Pulaski, Noble | | 50 |
| Cass, Berrien, St. Joseph, Elkhart, Marshall, Van Buren, La Porte, Starke, Lagrange, Kosciusko | | 40 |
| Cass, Berrien, St. Joseph, Elkhart, Marshall, Van Buren, La Porte, Starke, Lagrange | | 30 |
| Cass, Berrien, St. Joseph, Elkhart, Marshall | | 20 |
| Cass, Berrien, St. Joseph | | 10 |

Average Service Time and Wait Time

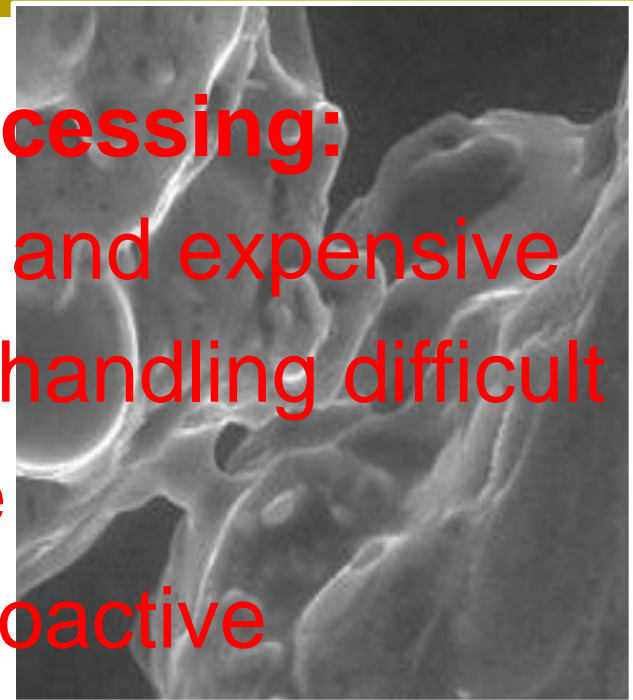
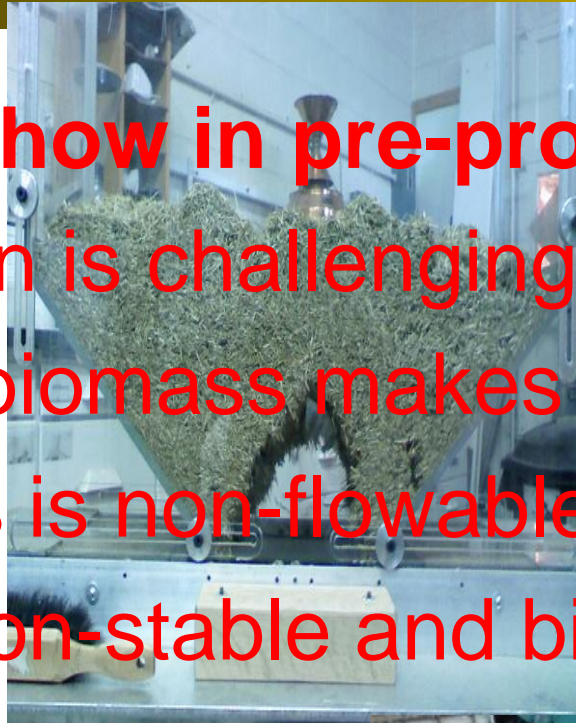


Model Validation is an issue, especially with no existing logistics supply chain !!!

Challenges with biomass feedstock handling

Lack of know-how in pre-processing:

- Size reduction is challenging and expensive
- Low density biomass makes handling difficult
- Bulk biomass is non-flowable
- Biomass is non-stable and bioactive

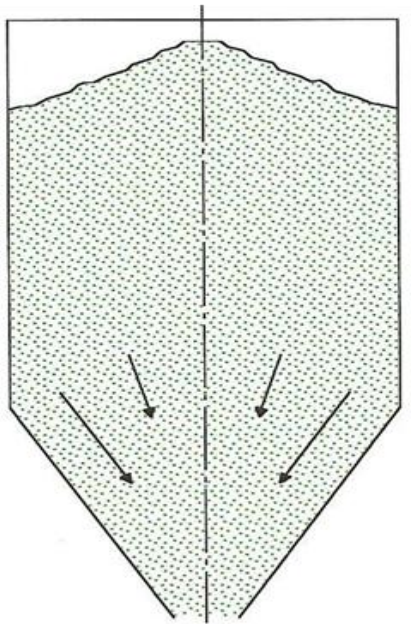


Importance for designing for unobstructed flow

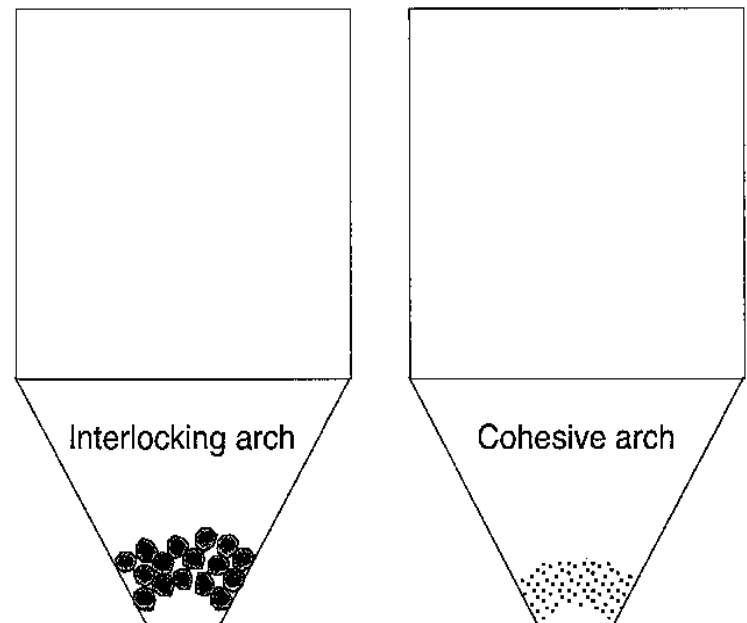
- In most plants processes, materials are transferred between unit processes or fed into reactors using storage vessels with discharge hoppers
- Common problems which occur in plants are interruption to flow from discharge orifices due to bridging, material compaction and caking.
- These problems results in production stoppages and can cost millions of dollars in lost revenue

Difference between flowable and non-flowable bulk

Flowable



Non-flowable



Differences between a flowable bulk and non-flowable biomass bulk

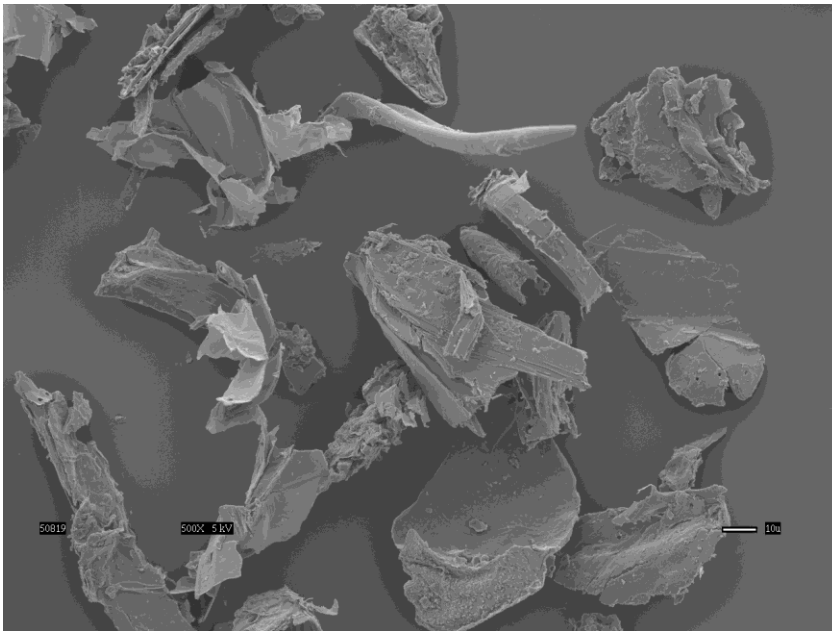
Flowable

- Particles move in discrete elements
- Will flow freely from a hopper
- Dividing samples manually or with automatic dividers is easy
- Physical properties tests are relatively easy

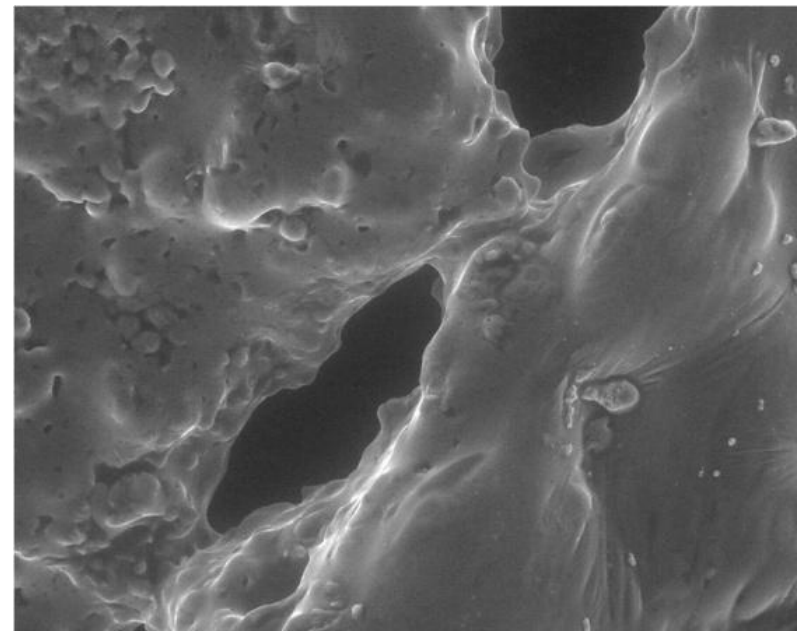
Non-flowable

- Particles move in packets of interlocking particles
- Will not flow freely from a hopper
- Difficult to sample manually or with dividers
- Physical properties can be difficult due to poor flow material
- Particles are hygroscopic

Biomass Particles – interlocking and caking tendencies



Corn stover particles exhibit interlocking

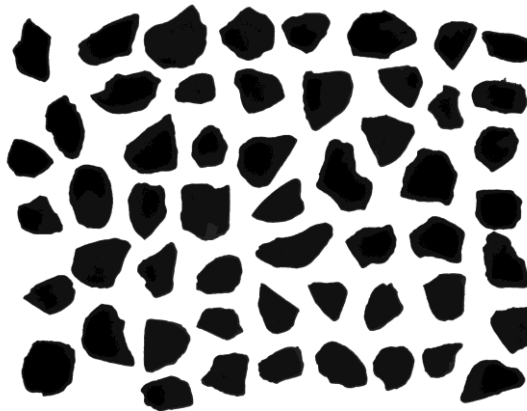


DDGS particles exhibit caking

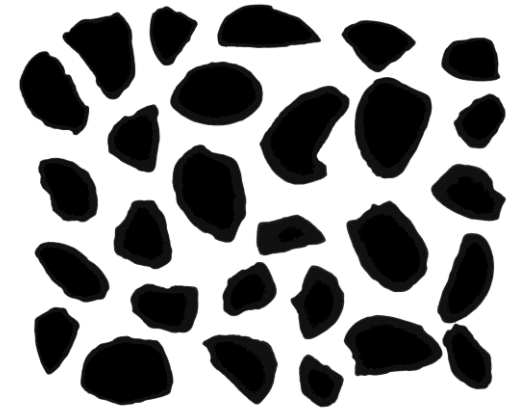
Particle morphology matters



Ground Switchgrass



Ground Corn kernels



Ground Soybean Seeds

Source: Ogden, C.A., K.E. Ileleji, and F. A. Richardson. 2009. Morphological properties and breakage behavior of three ground biofeedstocks by hammermilling. *Transactions of the ASABE* 53(1): 199-204

Changes in morphology of switchgrass grinds

| Hammermill | | | |
|--------------------|--------------------|---------------------|------------------|
| | Circularity | Aspect Ratio | Roundness |
| Screen Size | | | |
| 6.4 mm | 0.26 ± 0.04 | 9.72 ± 1.4 | 0.14 ± 0.02 |
| 3.2 mm | 0.21 ± 0.02 | 12.09 ± 0.7 | 0.11 ± 0.004 |
| 1.6 mm | 0.26 ± 0.05 | 10.28 ± 2.5 | 0.15 ± 0.04 |
| F value | 0.04 | 0.10 | 0.08 |
| P-value | 0.84 | 0.76 | 0.78 |

Source: Ogden, C.A., K.E. Ileleji, and F. A. Richardson. 2009. *Transactions of the ASABE* 53(1): 199-204

Flow Behavior of Biomass Particles



Biomass bulk particles are difficult to meter and feed through hoppers

Challenges include particle interlocking and nesting

Particles flow in detached packets (or nests) rather than in discrete elements

High bulk porosity (voids), compressibility and low bulk density

New theories to define the flow behavior of bulk biomass particles are needed !

Systems Approach to Biofeedstock Conversion



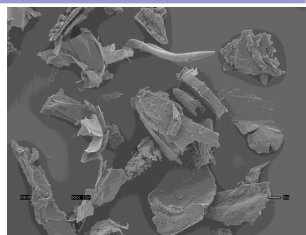
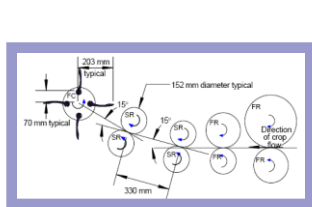
Biomass Solids Handling



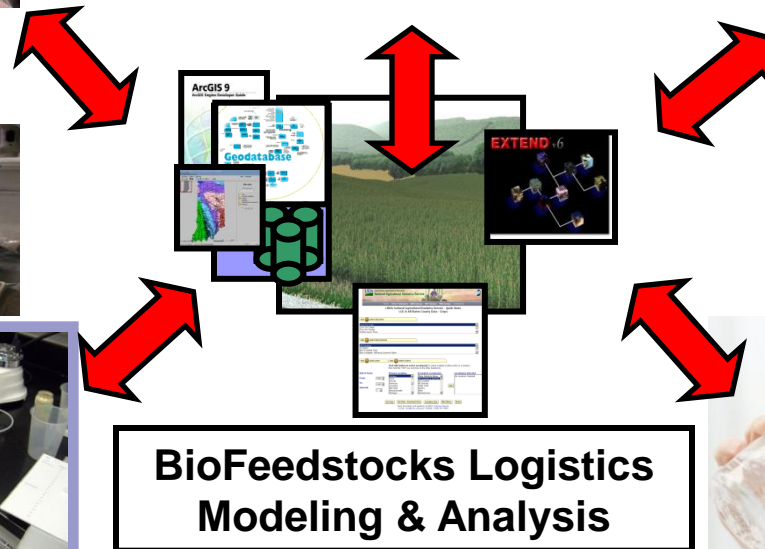
Food, Feed & Fuel



Cropping Systems



Basic Integrated Research



Agriculture & The Environment

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